Penning effects in Xenon gas mixtures:

survey of the homonuclear associative ionisations

Özkan ŞAHİN
Uludağ University Physics Department
Bursa -TURKEY

Measuring the transfer probabilities

- Townsend coefficient adjustment

$$G = \exp \int_{\text{tube}}^{\text{anode}} \mathrm{d}r\, \alpha(E(r)) \frac{\sum \nu_i^{\text{ion}}(E(r)) + \sum r_i\, \nu_i^{\text{exc}}(E(r))}{\sum \nu_i^{\text{ion}}(E(r))}$$

- r_i transfer probabilities: assuming α proportional to the sum of ν_{ion},
- α, ν_i : gas properties (pressure, temperature …)
- calculated by Magboltz [S.F. Biagi, *NIM A* **421** (1999) 234–240.]

Gain calibration

- uncertainty on the absolute gain,
- work function,
- calibration of the equipment.

$$G := g\, G$$

Photon feedback

- secondary avalanches,
- at high gain,
- almost uncorrelated, free parameter.

$$G := G / (1 - \beta G)$$

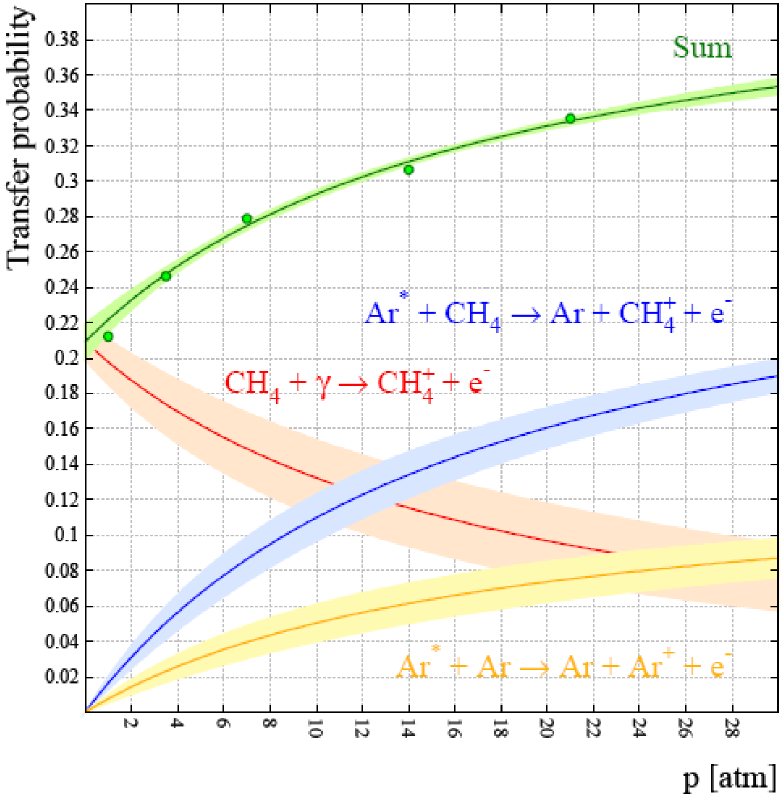
Energy transfer processes

- The following can happen for an A^*:
  - $A^* + B \rightarrow A + B^+ + e^-$: collisional ionisation,
  - $A^* + A \rightarrow A_2^+ + e^-$: homonuclear associative ionisation,
  - $A^* \rightarrow A + \gamma$: radiative decay

$$r = \frac{pc\,\frac{f_{B+}}{\tau_{A^*B}} + p(1-c)\,\frac{f_{A+}}{\tau_{A^*A}} + \frac{f_{rad}}{\tau_{A^*}}}{pc\,\frac{f_{B+}+f_{\bar{B}}}{\tau_{A^*B}} + p(1-c)\,\frac{f_{A+}+f_{\bar{A}}}{\tau_{A^*A}} + \frac{1}{\tau_{A^*}}}$$

A^*- B **A^*- A** **A^*- γ**

- Separations of the processes with pressure and concentration dependence of the transfer rates.
  - lim p → 0, r → radiative transfer



Experimental Gain Data

1- **Xe – CH_4**

2- **Xe – CO_2**

3- **Xe – Ar**

4- **Xe - Ar – CH_4**

5- **Xe – C_2H_2**

6- **Xe – iC_4H_{10}**

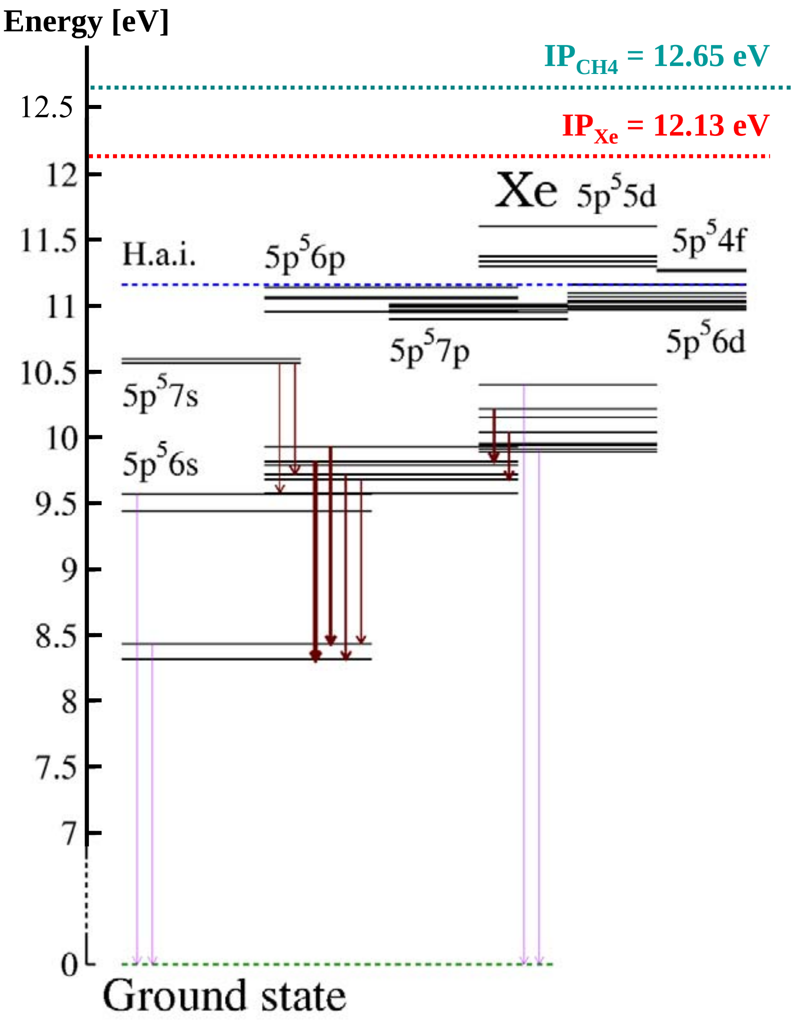
7- **Xe – iC_2H_4**

- Single wire proportional counters:
  - R.W. Hendricks,
    Nucl. Instr. And Meth. A **102** (1972) 309–312.
  - Z. Ye et al.,
    Nucl. Instr. and Meth. A **329** (1993) 140–150.
  - R.K. Sood et al.,
    Nucl. Instr. and Meth. A **344** (1994) 384–393.
  - D.J. Grey et al.,
    Nucl. Instr. and Meth. A **527** (2004) 493–511.
  - R.K. Manchanda et al.,
    Nucl. Instr. and Meth. A **595** (2008) 605–615.

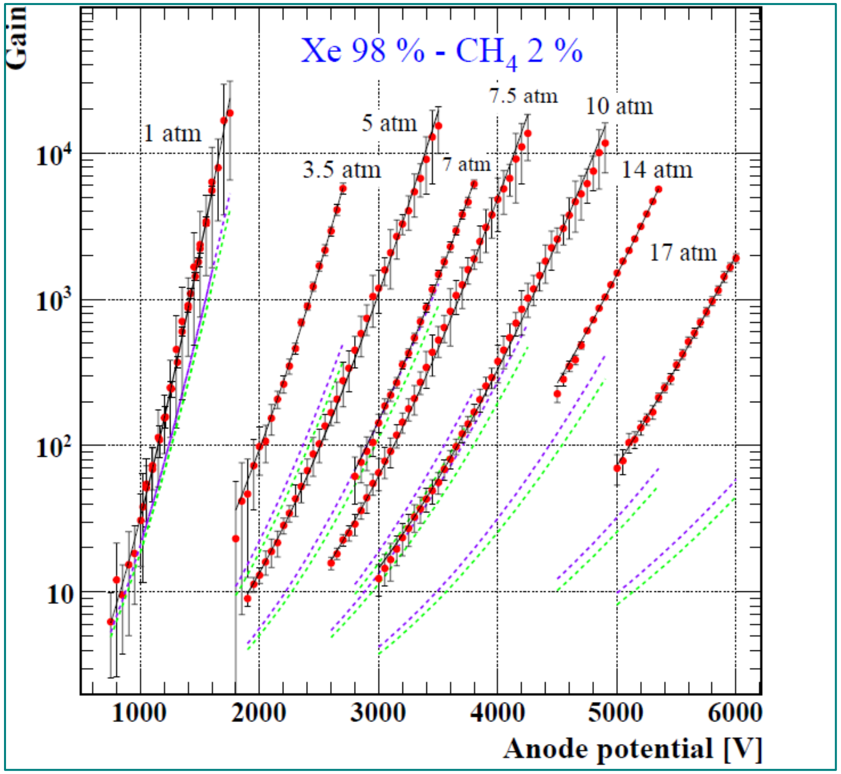
Xenon – Methane Mixtures

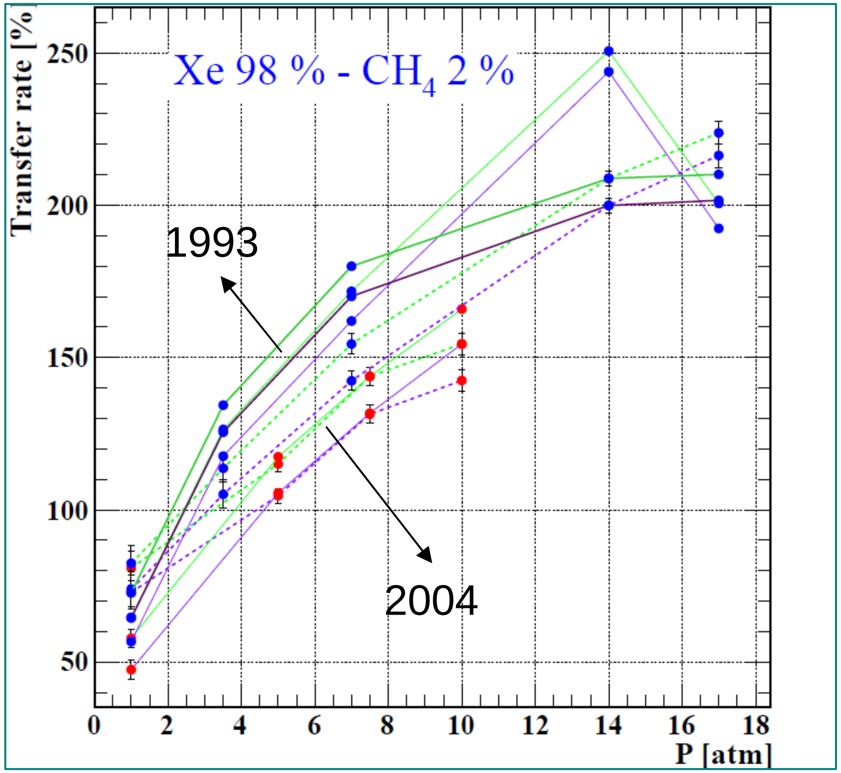
- $Xe^* + CH_4 \rightarrow Xe + CH_4^+ + e^-$
  NOT possible process energetically

- $Xe^* + Xe \rightarrow Xe_2^+ + e^-$ can happen
  $\varepsilon > 11.162$ eV Xe* states can transfer



Xenon – Methane Mixtures



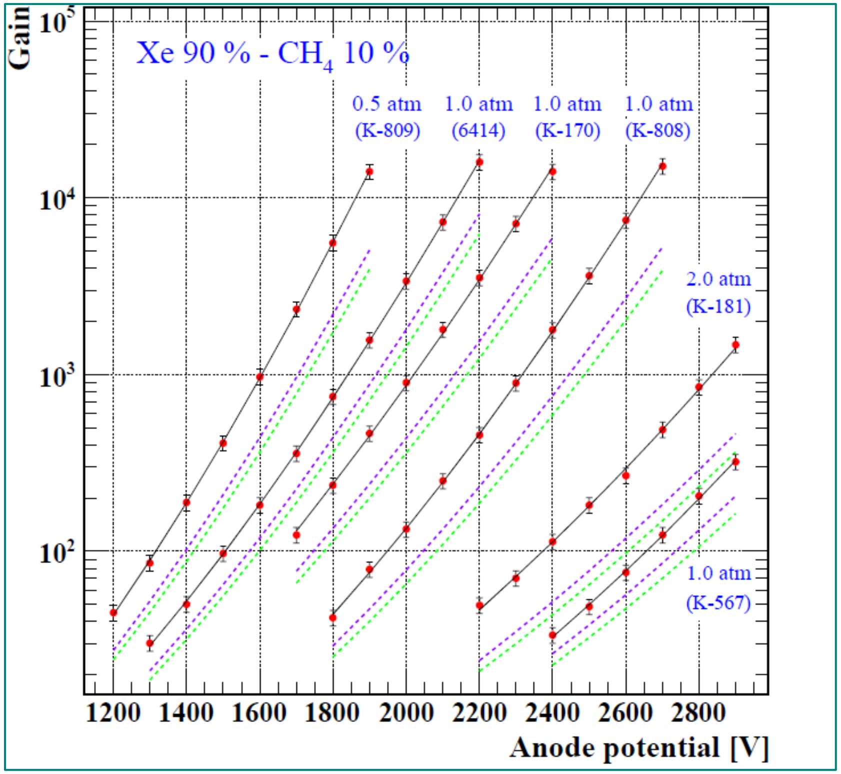


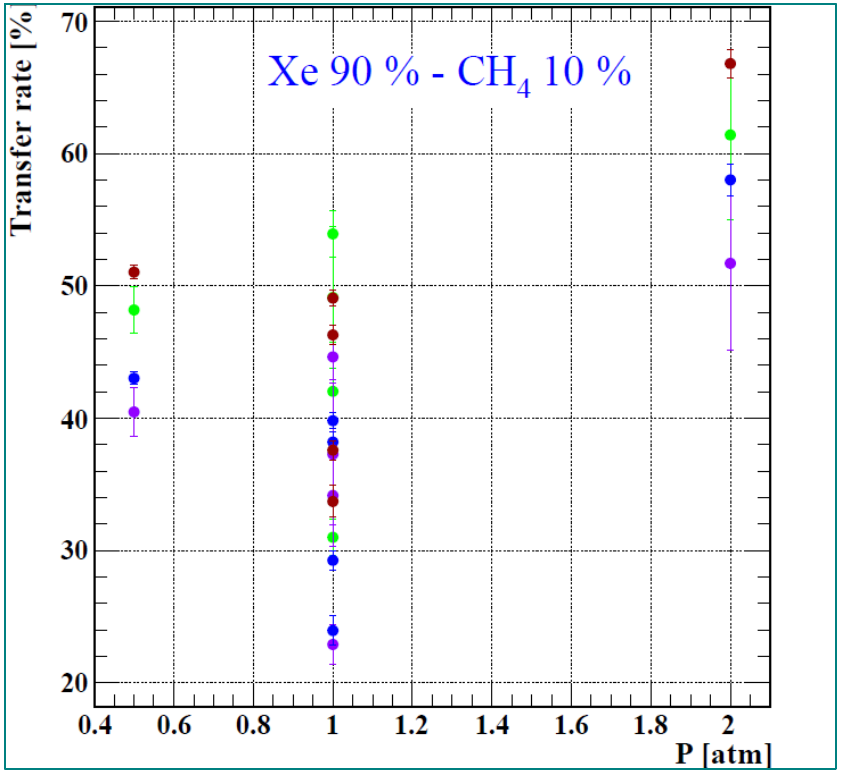
- r_a = 12.5 µm, r_c = 1.5 cm,
- No feedback

[Z. Ye et al., (1993), D.J. Grey et al., (2004)]

- Magboltz 8.9.3:
  - g_{w1} = 1.02 - 1.10, g_{w2} = 0.89
- Magboltz 8.9.1:
  - g_{w1} = 1.05 – 1.10, g_{w2} = 0.91
- Difference on transfer rates ≈ 12 %

Xenon – Methane Mixtures





- ❖ No feedback

Ser. No	r_c [cm]	r_a [µm]
K-809	1.27	25.4
6414	1.27	25.4
K-170	2.54	25.4
K-808	1.27	50.8
K-181	2.54	25.4
K-567	2.54	76.2

[R.W. Hendricks, 1972]

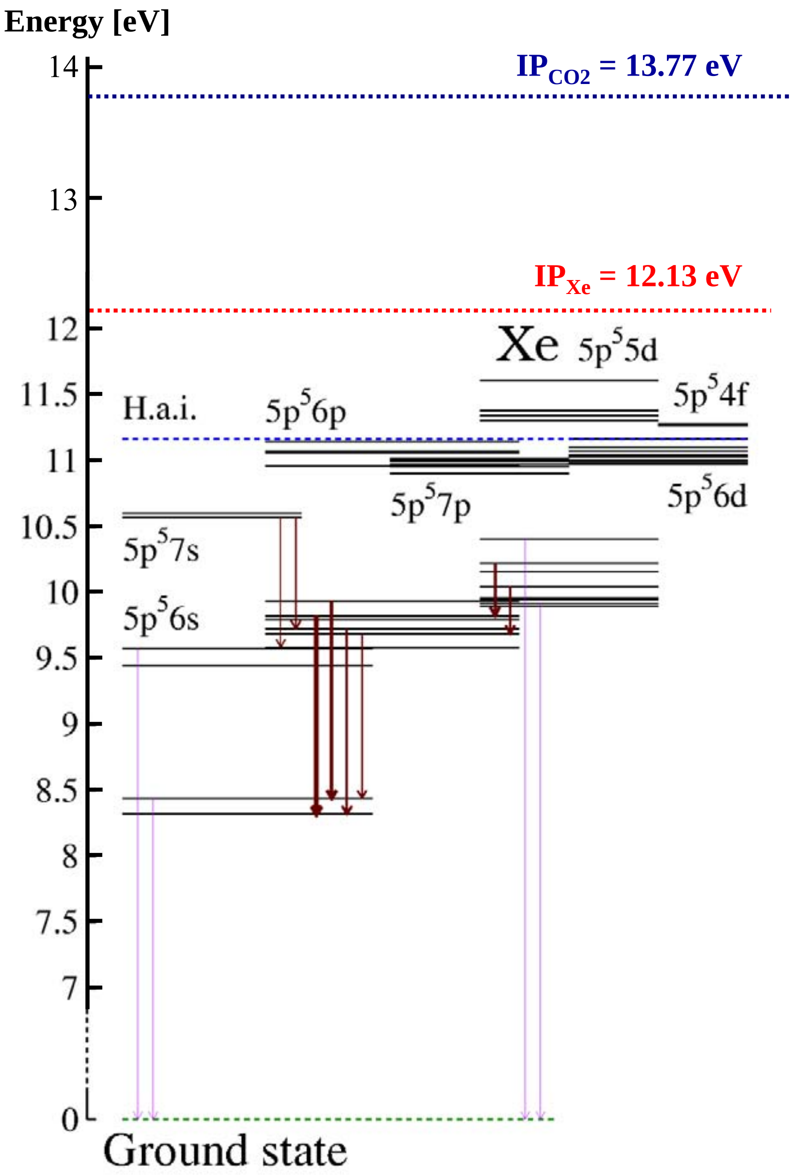
- ❖ Magboltz 8.9.3: $g_w = 0.973$
- ❖ Magboltz 8.9.1: $g_w = 0.996$
- ❖ Difference on transfer rates ≈ 8 %

- ❖ r ≈ 15-20 % differences at 1 atm ?
  - ❖ applied voltages

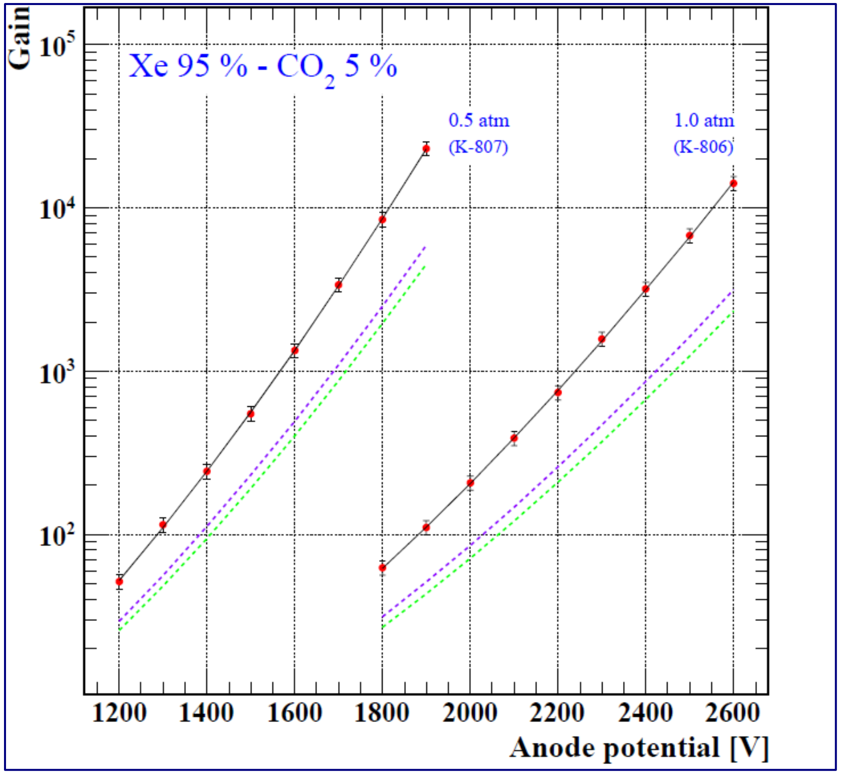
Xenon – CO_2 Mixtures

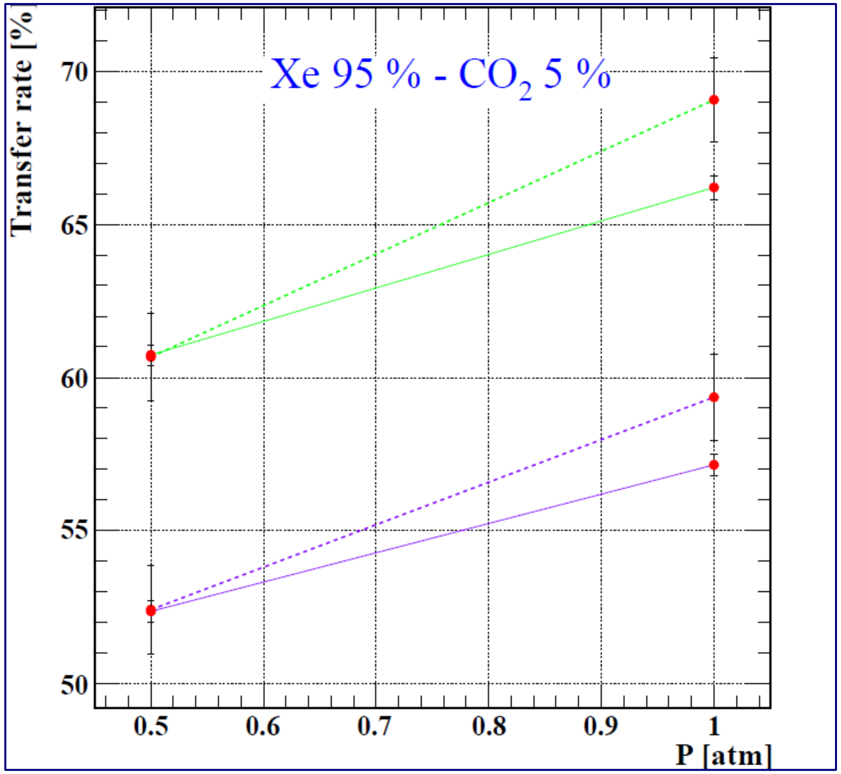
- $Xe^* + CO_2 \rightarrow Xe + CO_2^+ + e^-$
  NOT possible process energetically

- $Xe^* + Xe \rightarrow Xe_2^+ + e^-$
  $\varepsilon > 11.162$ eV Xe* states can transfer



Xenon – CO_2 Mixtures





- No feedback

Ser. No	r_c [cm]	r_a [μm]
K-807	1.27	50.8
K-806	1.27	50.8

- Magboltz 8.9.3: $g_w = 0.973$
- Magboltz 8.9.1: $g_w = 0.996$

- Difference on transfer rates ≈ 11 %

[R.W. Hendricks, *Nucl. Instr. And Meth. A* **102** (1972) 309–312.]

Xenon – Argon Mixtures

- $Ar^* + Xe \rightarrow Ar + Xe^+ + e^-$

  $\varepsilon > 12.13$ eV Ar* states can transfer

- $Xe^* + Xe \rightarrow Xe_2^+ + e^-$

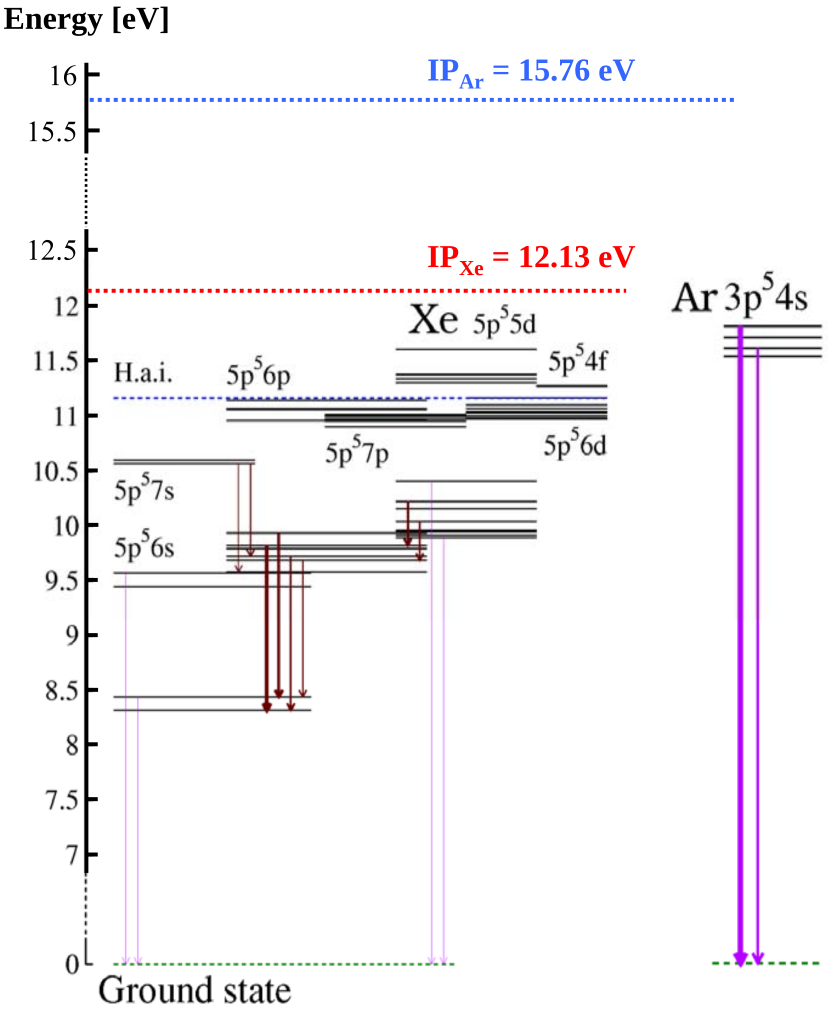
  $\varepsilon > 11.162$ eV Xe* states can transfer

- Also Ar* induced transfers are possible

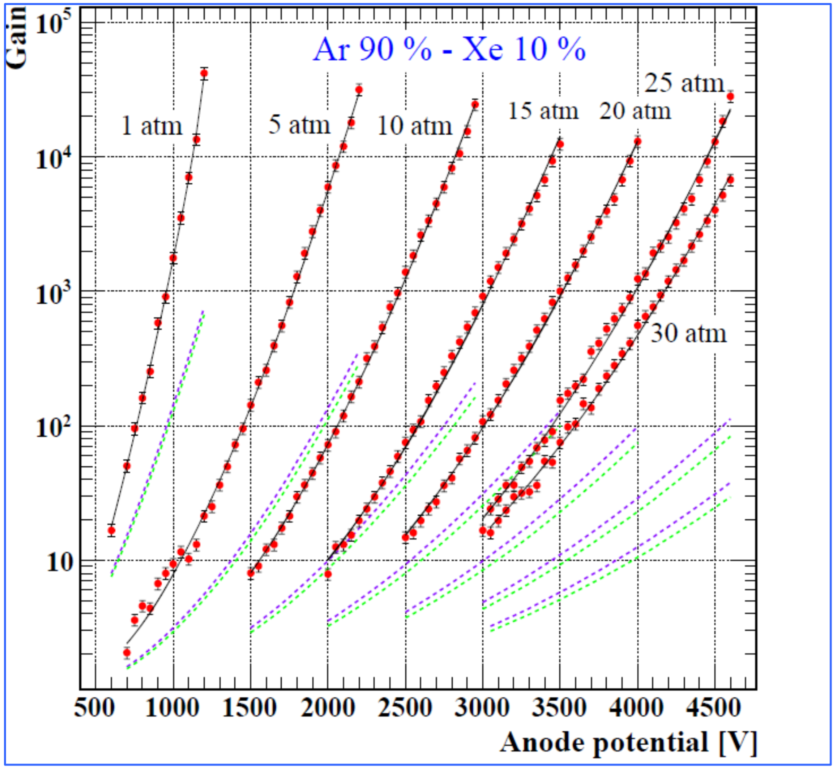
$$Ar^* + Xe \rightarrow Ar + Xe^*$$

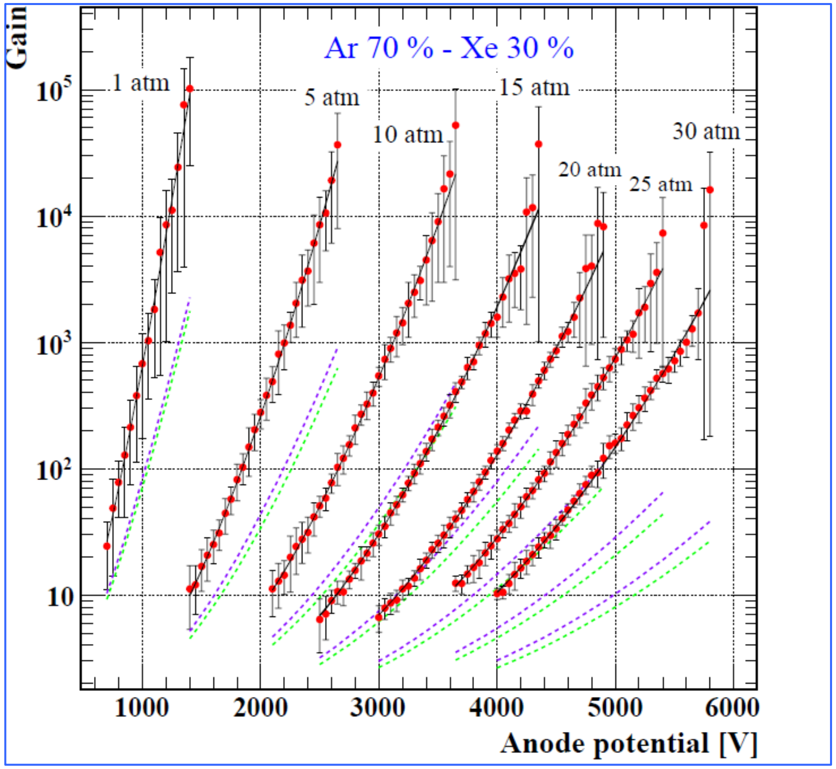
$$Xe^* + Xe \rightarrow Xe_2^+ + e^-$$

[Ö. Şahin et al. *JINST* **P05002** (2010) 1–30.]



Xenon – Argon Mixtures



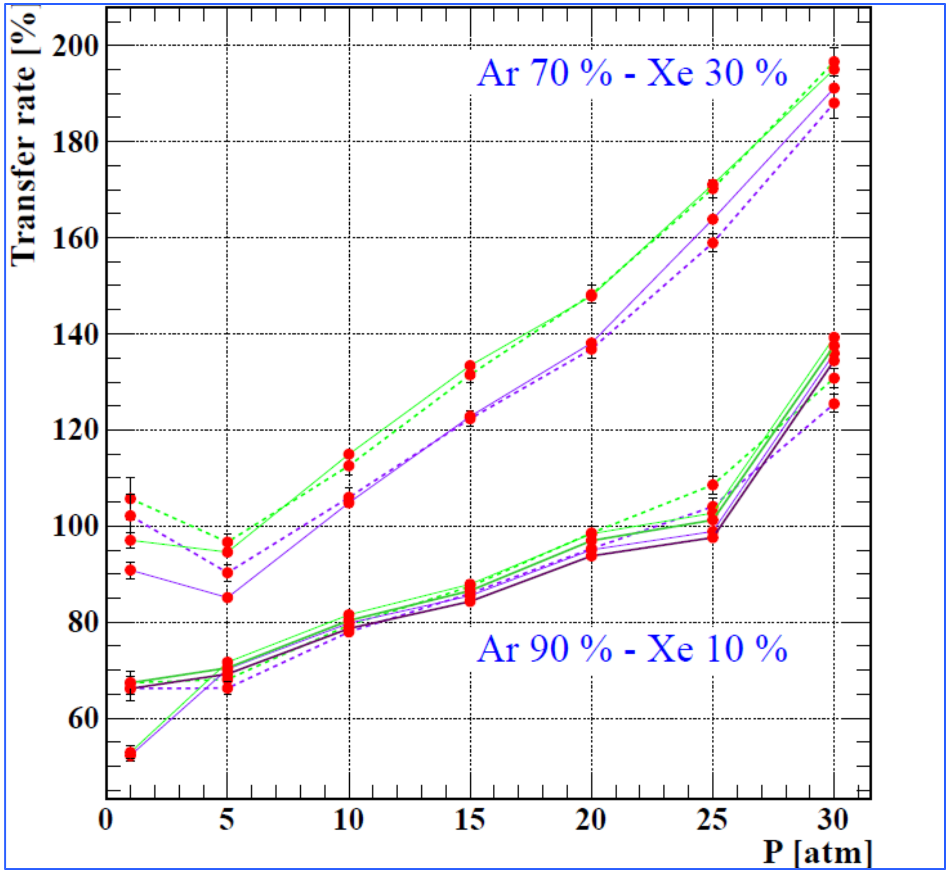


- r_a = 12.5 µm, r_c = 1.5 cm,
- Feedback at 1 atm for 10 % Xe
  - $1.05\ 10^{-5} \pm 0.30\ 10^{-5}$ (g free)

- Larger errors at high gains
- No feedback

[D.J. Grey et al., *Nucl. Instr. and Meth. A* **527** (2004) 493–511].

Xenon – Argon Mixtures



Ar 90 % - Xe 10 %

- Magboltz 8.9.3:
  - $g_{w1} = 0.88$, $g_{w2} = 0.93$
- Magboltz 8.9.1:
  - $g_{w1} = 0.92$, $g_{w2} = 0.97$
- Difference on transfer rates ≈ 2 %

Ar 70 % - Xe 30 %

  - $g_w = 0.86$, $g_w = 0.83$
- Difference on transfer rates ≈ 10 %

Xenon – Argon – Methane Mixtures

- ❖ $Ar^* + CH_4 \rightarrow Ar + CH_4^+ + e^-$

  $\varepsilon > 12.65$ eV Ar* states can transfer

- ❖ $Ar^* + Xe \rightarrow Ar + Xe^+ + e^-$

  $\varepsilon > 12.13$ eV Ar* states can transfer

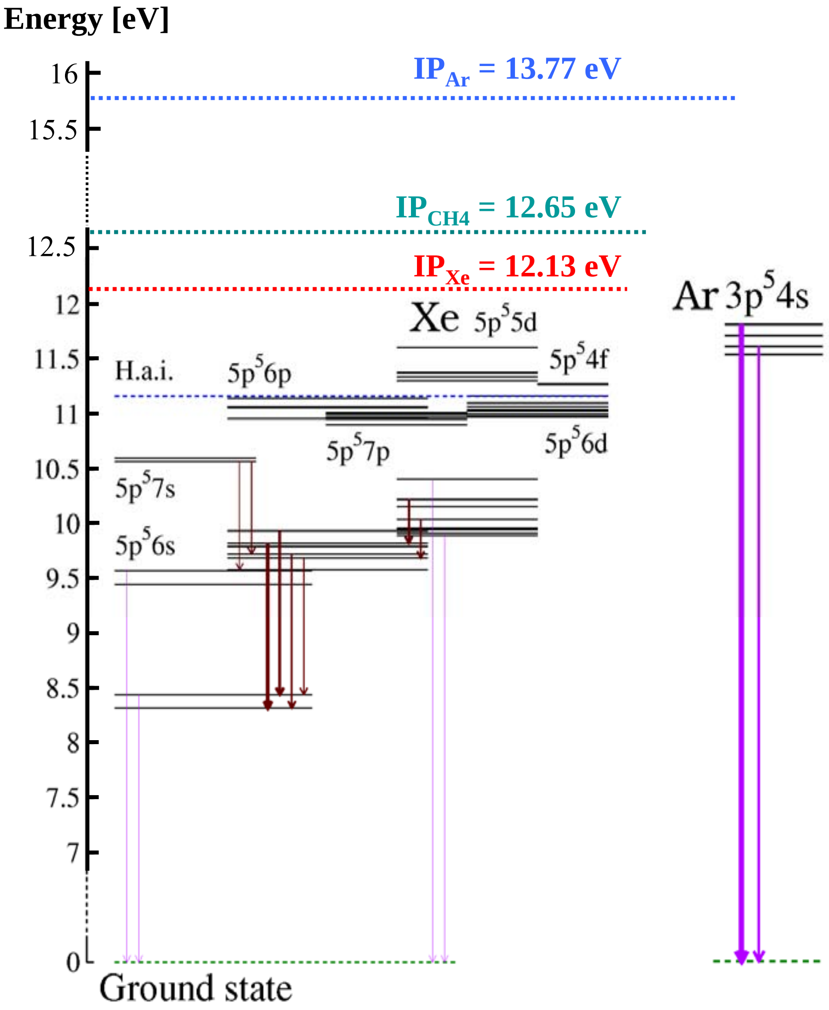
- ❖ $Xe^* + Xe \rightarrow Xe_2^+ + e^-$

  $\varepsilon > 11.162$ eV Xe* states can transfer

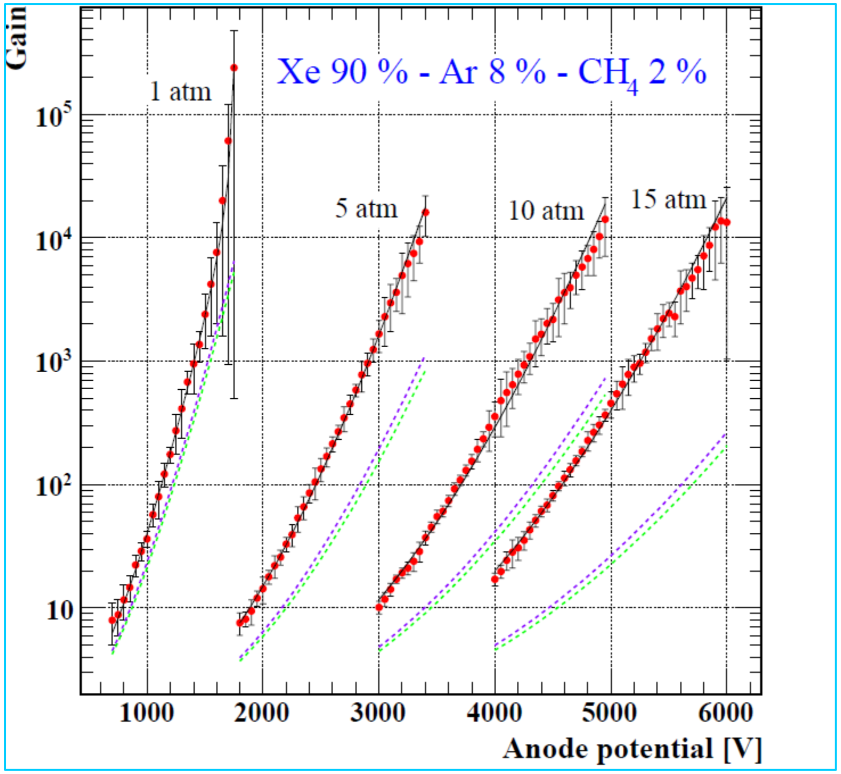
- ❖ Ar* induced transfers are possible

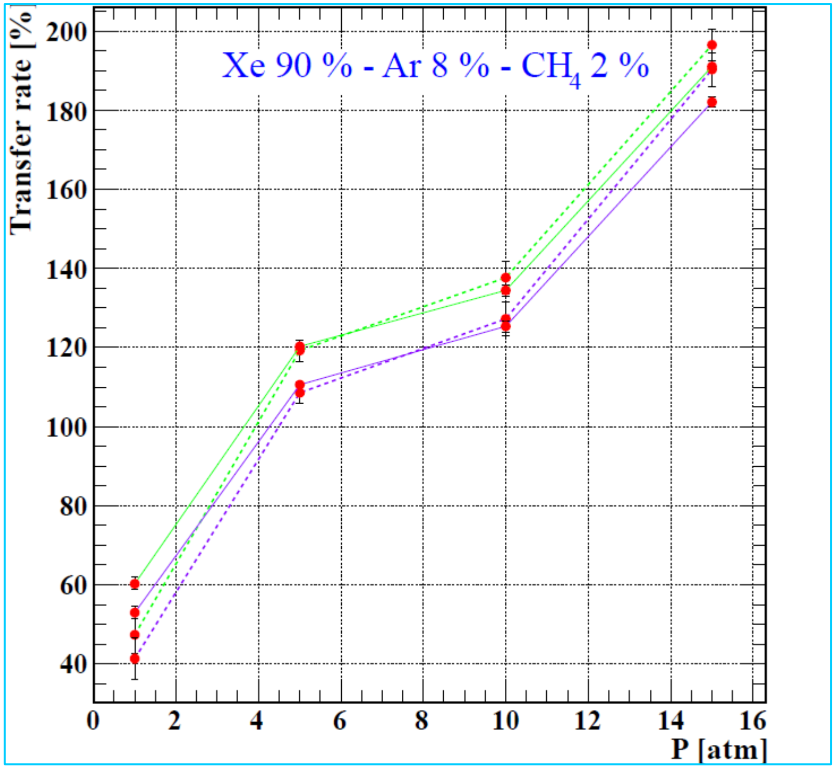
$$Ar^* + Xe \rightarrow Ar + Xe^*$$

$$Xe^* + Xe \rightarrow Xe_2^+ + e^-$$



Xenon – Argon – Methane Mixtures





- Feedback at 1 atm
  - $4.87\ 10^{-5} \pm 0.74\ 10^{-5}$ (g free)
    - Larger feedback term than Xe-Ar ?
      - Big errors at 1 atm

[D.J. Grey et al., (2004)].

- Magboltz 8.9.3: $g_w = 0.973$
- Magboltz 8.9.1: $g_w = 0.996$
- Difference on transfer rates ≈ 11 %
- Larger transfer rates than Xe-Ar mixtures at high pressures ?

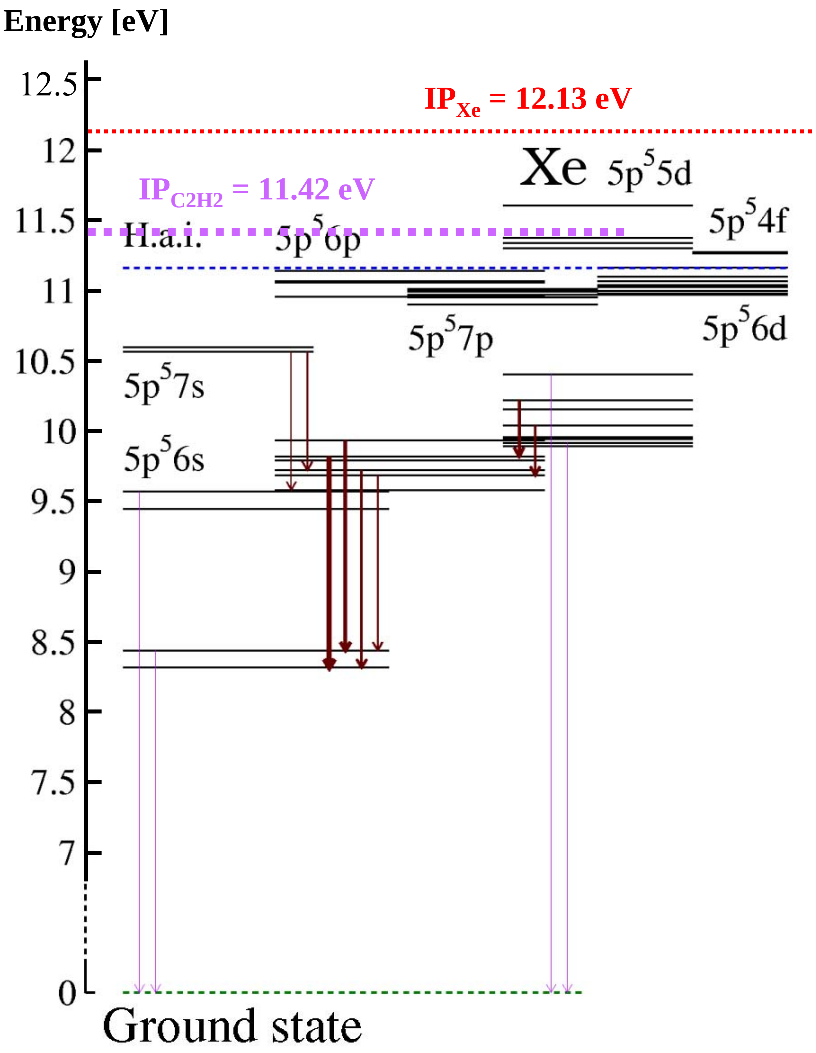
Xenon – Acetylene Mixtures

- $Xe^* + C_2H_2 \rightarrow Xe + C_2H_2^+ + e^-$

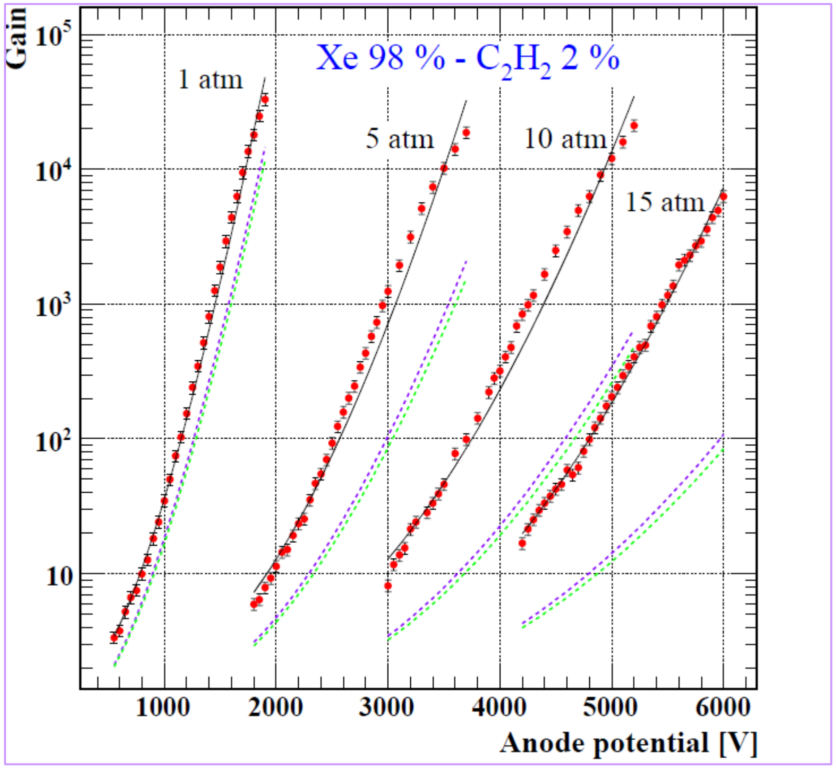
  $\varepsilon > 11.42$ eV Xe* states can transfer

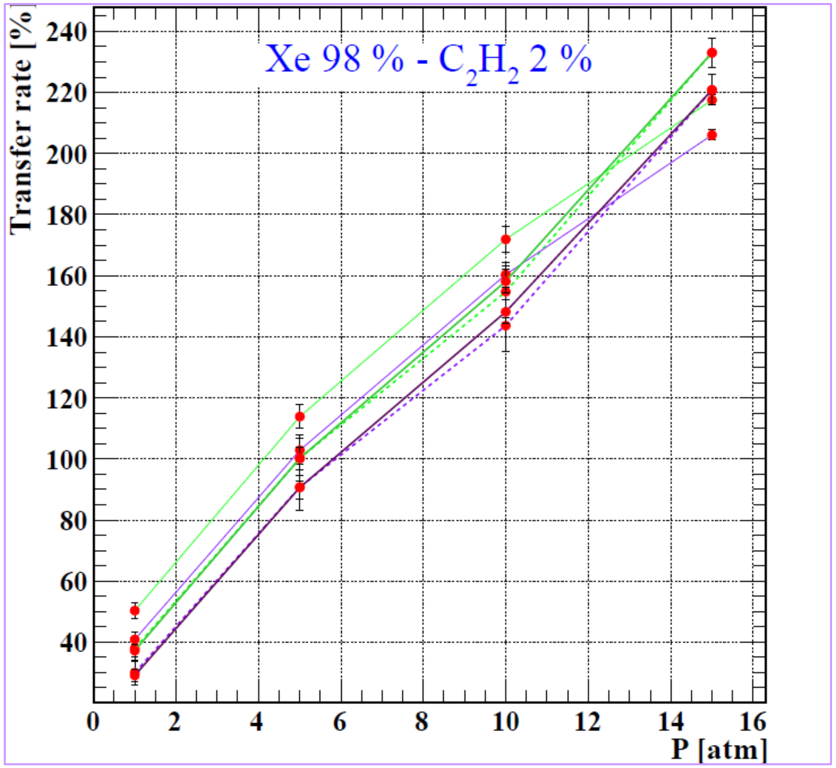
- $Xe^* + Xe \rightarrow Xe_2^+ + e^-$

  $\varepsilon > 11.162$ eV Xe* states can transfer



Xenon – Acetylene Mixtures





- ❖ No feedback
- ❖ r ≈76 % in Ar 98 % - C_2H_2 2% at 1 atm

[Ö. Şahin et al. *JINST* **P05002** (2010) 1–30.]

[R.K. Manchanda et al., 2008].

- ❖ Magboltz 8.9.3: $g_{w1,2} = 1.21, 1.51$
- ❖ Magboltz 8.9.1: $g_{w1,2} = 1.19, 1.54$
- ❖ Difference on transfer rates ≈ 10 %
- ❖ The largest transfer rates at high pressures

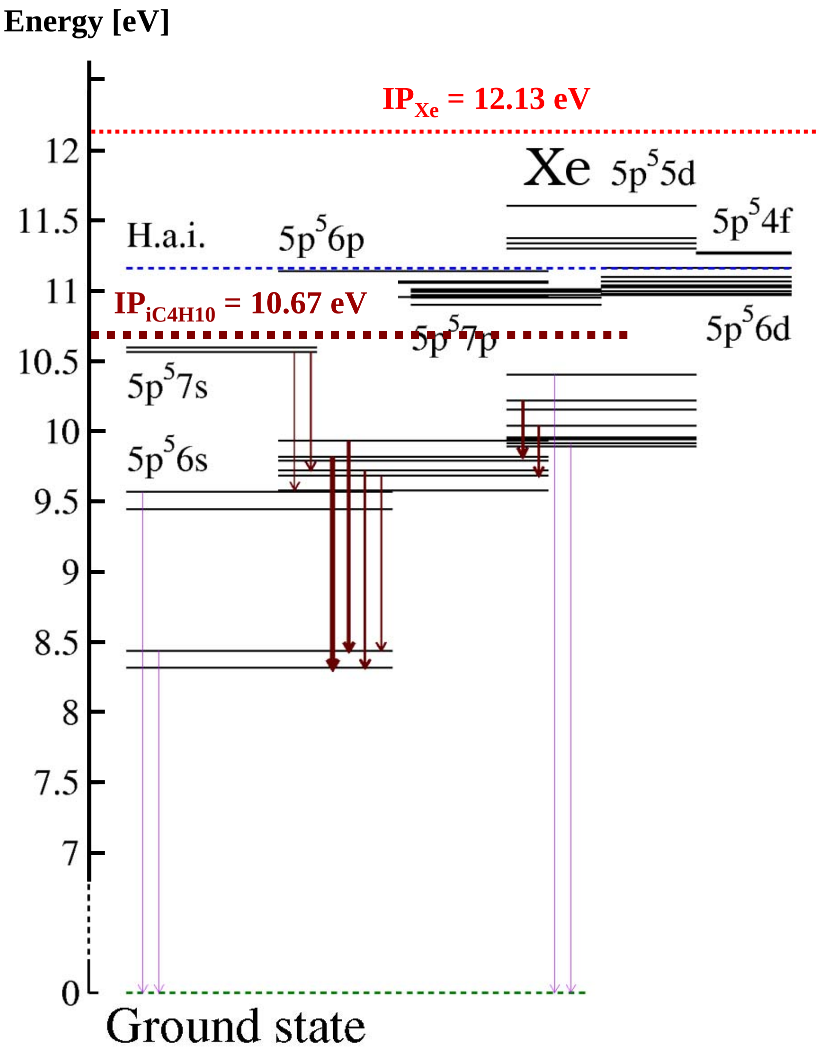
Xenon – Isobutane Mixtures

- $Xe^* + iC_4H_{10} \rightarrow Xe + C_4H_{10}^+ + e^-$

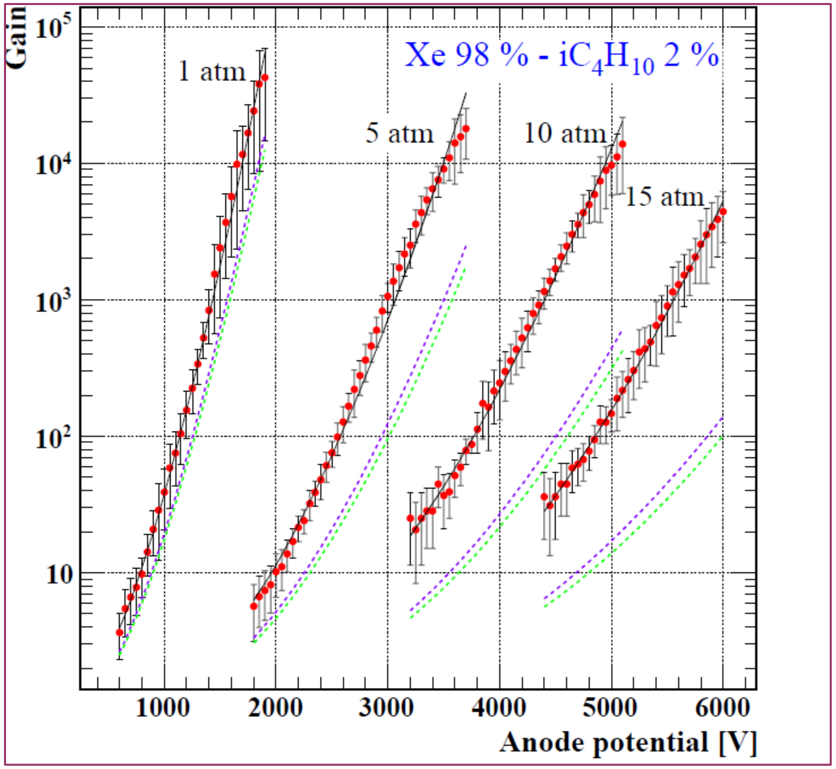
  $\varepsilon > 10.67$ eV Xe* states can transfer

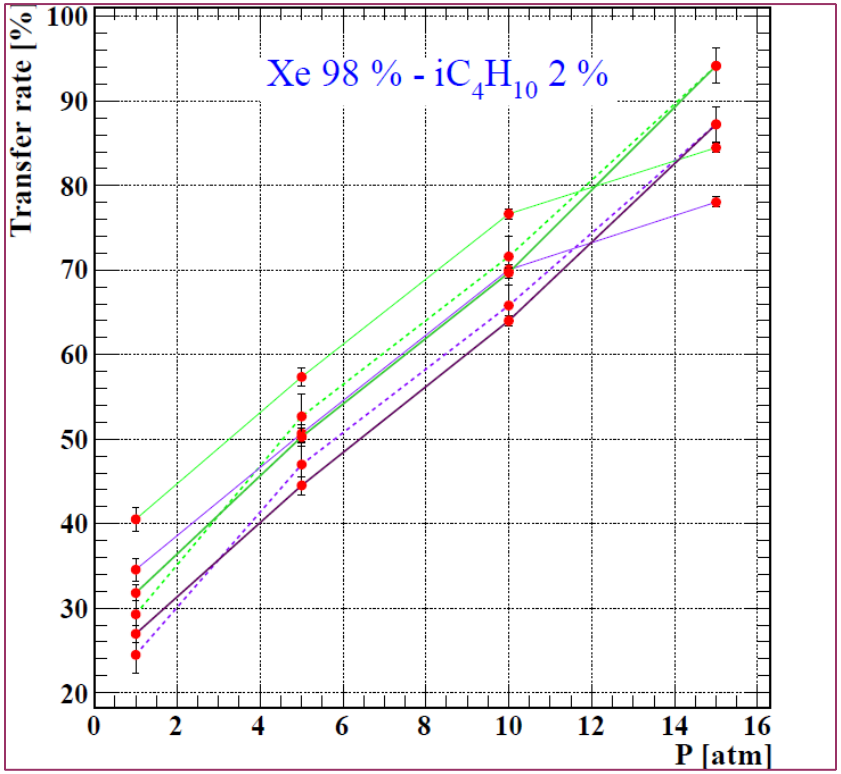
- $Xe^* + Xe \rightarrow Xe_2^+ + e^-$

  $\varepsilon > 11.162$ eV Xe* states can transfer



Xenon – Isobutane Mixtures





- No feedback

- Magboltz 8.9.3: $g_{w1,2} = 0.94, 1.18$
- Magboltz 8.9.1: $g_{w1,2} = 0.91, 1.19$

- Difference on transfer rates ≈ 7 %
- r < 100 % !!!

[D.J. Grey et al., 2004].

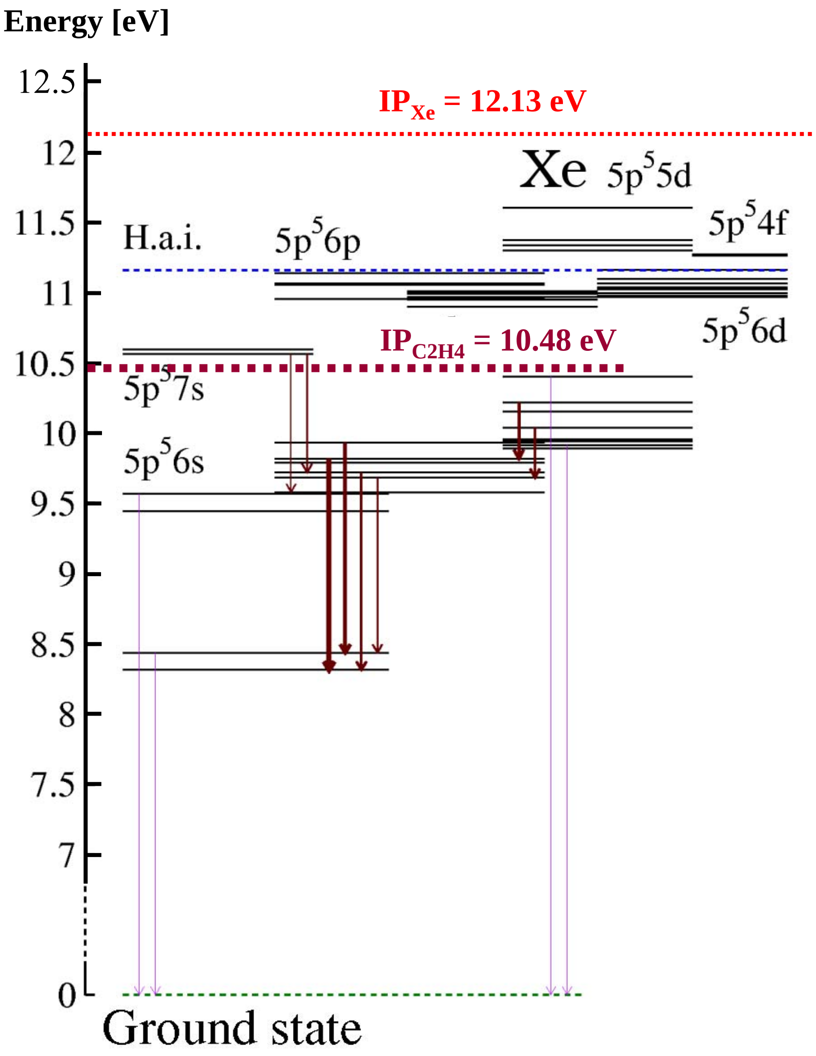
Xenon – Ethylene Mixtures

- $Xe^* + C_2H_4 \rightarrow Xe + C_2H_4^+ + e^-$

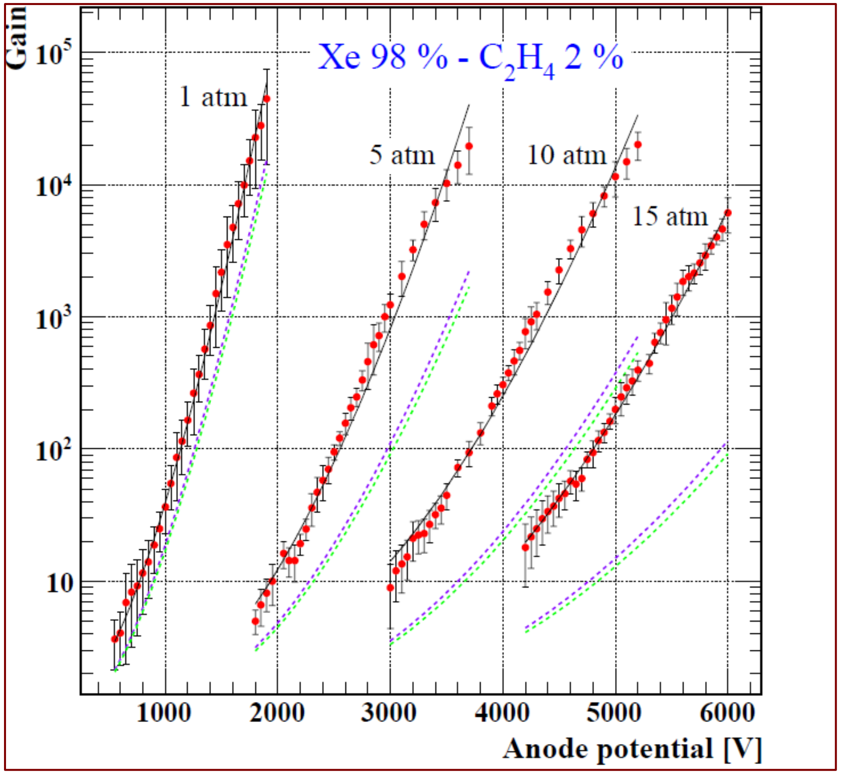
  $\varepsilon > 10.48$ eV Xe* states can transfer

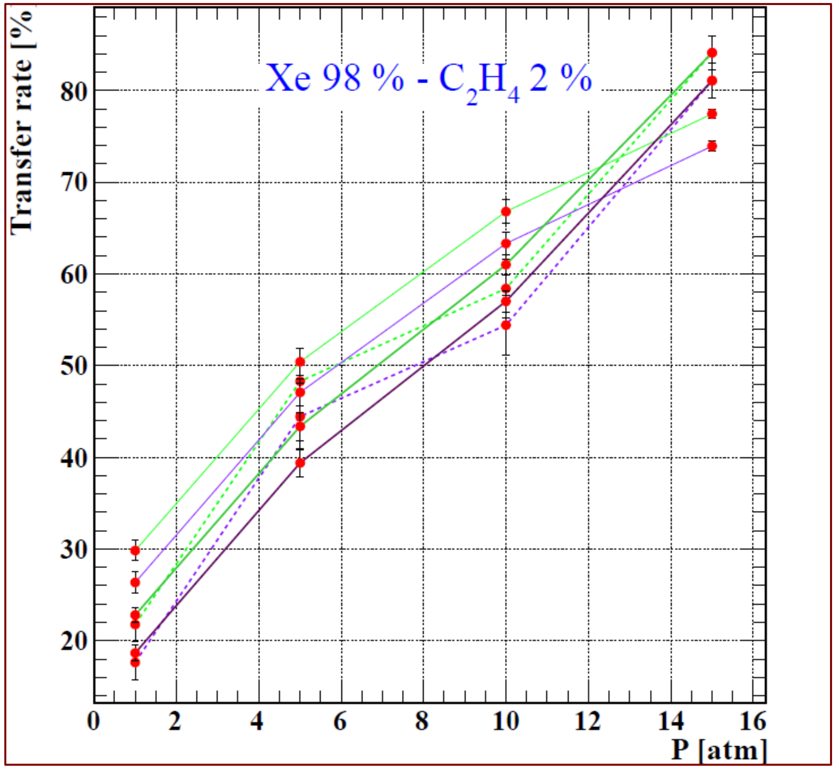
- $Xe^* + Xe \rightarrow Xe_2^+ + e^-$

  $\varepsilon > 11.162$ eV Xe* states can transfer



Xenon – Ethylene Mixtures





- ❖ No feedback

- ❖ Magboltz 8.9.3: $g_{w1,2} = 1.04, 1.40$
- ❖ Magboltz 8.9.1: $g_{w1,2} = 1.07, 1.41$
- ❖ Difference on transfer rates ≈ 4 %

- ❖ The lowest transfer rates !!!
  - ❖ The lowest ionisation potential of C_2H_4

[D.J. Grey et al., 2004].

Conclusions

- Pressure dependence of transfer rates,
- Large transfer rates (r > 100 % many times)
    - homonuclear associative ionisations,
- Next
    - need to understand the rates with transfer model,
    - separation of the transfer processes.

Thank you …